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CONVERSION OF TWO ROTOR WANKEL ROTARY ENGINE TO SINGLE ROTOR EXPERIMENTAL ENGINE AND PRELIMINARY RESULTS

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Keywords: Wankel Engine, Rota Rotary engines, Single rotor Wankel engine, Intake manifold, Injection time.
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ABSTRACT

In experiment, the last model of Wankel Rotary engine of Mazda Company, RX-8 13B is used as experimental engine. The purpose of using this model between the rotary engines is either the availability of replacement parts or to be a new generation of this type engines. The original RX-8 is a two rotor engine but it has been converted to a single rotor experimental-research engine. Among this conversion, the design and production of intake and exhaust manifolds, cooling and lubrication system has been performed. In addition, production of an electronic control unit specified for single rotor engine and alteration of other change-needed parts like eccentric shaft has been accomplished. On intake manifold of this single rotor engine, there are four intake channels and in order to be like as Manifold-Injection original RX8 engine, for each channel one fuel injector has been placed. In result, conversion to a single rotor experimental engine has been finished. In this experiment the engine has been tested in different points of speed and load, with one open channel and one injector. The fuel is injected in different angles of the eccentric shaft. The effect of changing the time of injection on specific fuel consumption and emissions has been investigated. As a result, a number of experiments are conducted on the Wankel engine and It is observed that positive results are obtained

INTRODUCTION

Wankel engine is named as rotary piston engine working with four stroke principle. In 1954, NSU-Wankel rotary piston engine is successfully developed by Felix Wankel. After that by placing in the stand of the motorcycle manufacturer, NSU (now is named Audi), it has announced its name to automotive sector. Wankel engine operation mode is different from conventional piston engines. Moving parts of the Wankel engine are only the rotor and eccentric shaft. The rotor is placed on the eccentricity of the shaft. Due to the centrifugal movement of the eccentric shaft, the rotor works with an eccentric movement. The force achieved from the rotor transfers to the eccentric shaft directly.

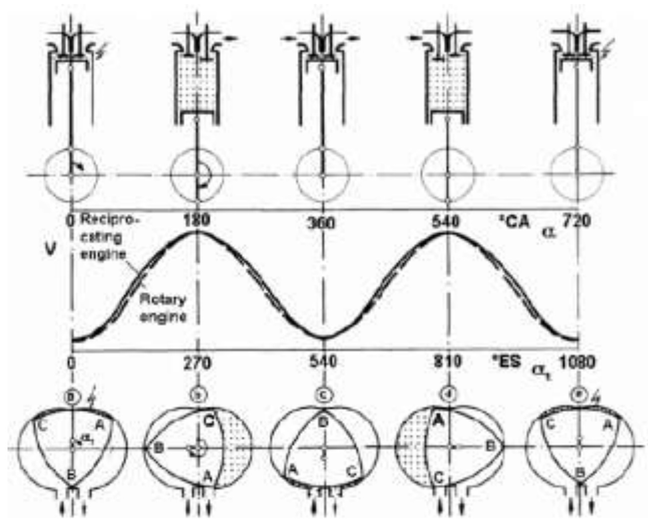

Figure 1: Comparison of the Wankel and reciprocating engine [1].

In figure 1 it can be seen that one cycle of Wankel engine is done by rotation of the rotor in the engine housing. In Wankel engine one full orbit of the rotor equates to three turns of the eccentric shaft. There is one combustion stroke for each rotation of the shaft. In classic reciprocating piston engines, there is one combustion stroke for two turns of the crankshaft. So power density in Wankel engine is higher than the conventional

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engines. In this type engine, intake and exhaust actions are done by the ports placed on the engine body; instead of camshaft-valve mechanism of reciprocating piston engines. The opening and closing time of the intake ports is controlled by the surface of the rotor. The rotor performs the function of crank mechanism so by eliminating this system, it has a simple mechanism and it is much lighter than conventional engine and also it can rotate in high speeds. Another advantage of the Wankel engine is due to low number of parts, it is smaller and needs less space and producing more power than the same weight reciprocating piston engine. Lower NOx emissions, lower vibration due to eliminating the reciprocating masses, are the other advantages of this type engine [2-4]. By considering the advantages of today Wankel engine, it can play an important role in range extenders and specially in unmanned aerial vehicles, where it is needed to have a low vibration and high power density. Moreover, Mazda Company, which is using the Wankel engine in its producing passenger cars, is performing serious researches and developments on this type engines. By obtaining from the performing researches and developments on this type engines, more application of Wankel engine in the future could be predicted.

CONVERSION TO SINGLE-ROTOR ENGINE

In this research the base of the experimental engine is RENESIS RX8 13B of MAZDA company. Our reasons for choosing this engine are first availability of the replacing parts, then the engine's dimensions fit to the needing measuring instruments, and also it is a new type of engine. About RX8 Wankel engine, Ohkubo et. all. presented comprehensive information [5]. The power absorbing capacity of the engine brake in the laboratory is 70kW. The power of the RX8 engine is about 170kW and due to this, the capacity of the existing dynamometer is not enough for this engine. Moreover, a single rotor engine is more suitable for experimental purposes so the two rotor engine is converted to single rotor engine. Among this conversion, adopting the eccentric shaft, intake and exhaust manifolds, cooling and lubrication systems, electronic control unit and alteration of other change-needed parts like eccentric shaft has been accomplished or new parts specified for single rotor engine has been produced.

During this process, firstly the design of the eccentric shaft specified for single rotor engine has performed then two-rotor engine shaft has been modified to the single rotor shaft. In this modification, new oil flow channels are placed to feed the bearings and other parts on this shaft. After that heat treatment process is performed on the operated surfaces of the shaft and finally the eccentric shaft has converted to the single rotor shaft.

Figure 2: Conversion of two-rotor engine eccentric shaft (above) to single-rotor eccentric shaft (bottom).

Then, the static and dynamic balancing processes have been done on the engine. During the dynamic balance, the balancing mass on the flywheel has been decreased, and an extra mass has been added to the pulley placing in front of the engine. In the testing process, it has been seen that the balancing process has done successfully.

The first thing that has changed in lubrication system is oil filling pipe which has been produced; and also a hole for oil dipstick is placed on engine body and a part has produced for this place; this hole is designed in the way that a sensor for measuring the temperature of oil (which is one of the data that has measured in the experiment) can be placed into it. In the lubrication system of RX-8 engine a metering oil pump has been used to send certain amount of oil through the oil nozzles according to the load and speed. Regarding to the researches, it has been decided to mix two-stroke engine oil with fuel in specified ratio to lubricate the surface between the trochoid and apex seals, instead of sending the oil with nozzles into the body [6-8]. By this lubricating method the combustion will be cleaner and it will not leave deposits on seal and rotor surface. On the engine housing instead of oil nozzles, sensors have been placed which can measure the pressure of combustion chamber at intake and early part of compression strokes. Oil filter connection, oil pan and heat exchanger for oil cooling are adapted on single rotor test engine.

Next step was the exhaust manifold design. It has been decided to produce a separated type (Headers type) manifold. So at first it designed in Solidworks and then it has been produced in the intended dimension. For measuring exhaust pressure and temperature, sensor locations have been placed on the manifold;

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in order not to block the dynamic flow in the manifold, these locations have been placed on side wall.

(**a**)

(**b**)

Figure 3: The design of the exhaust manifold in the single-rotor test engine (a) and manufactured (b).

Intake manifold for this single rotor engine has been designed by the dimensions of the original engine. In this manifold, four intake channels and four fuel injector for each, and for three of these channels (Two auxiliary and 1 secondary) there are three valves. In figure 4 it is shown that there are black colored pipes on intake channels which have been tightened with clamps. By these black pipes the length of the manifold can be adjusted. Moreover, in the sequel of the manifold there is a plenum (air reservoir) and a throttle valve. In the figure 4 it can be seen the produced and assembled intake manifold.

Variables like injection and ignition time, ignition coil filling time (dwell time) are controlled with a computer by an electronic unit which is designed for single-rotor test engine. It is needed to have an interface to control the ignition time and injection duration. As a micro controller card, Arduino Mega 2560 has been chosen [9]. To boost the ignition and injection signals a controller card including driver relays is designed. As a driver relay, by receiving the signals from Arduino, it works like a classic switch to trigger the injection and ignition systems. This relays are Solid State type (SSR) that allows to switching action in millisecond intervals. To define the time of injection and ignition and rotation speed there is an encoder connected to the eccentric shaft. Moreover, this encoder sends a reset signal for each turn of the shaft. By using this signal, the time of the end of the compression (Top Dead Center, TDC) is defined. For measuring the fuel flow characteristic of injectors, an experimental setup is formed. Additionally, ignition coil, encoder (by an electromotor) and the electronic control unit preliminary tests has been performed [10]. By performing the preliminary tests successfully, the electronic control unit has been assembled to the engine.

(a)

(b)

Figure 4: Intake manifold and its view (a) unassembled and (b) assembled on the engine.

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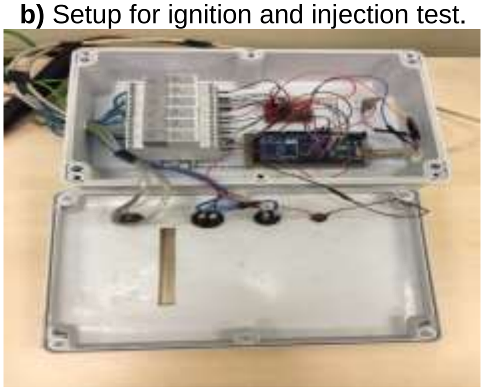
a) Encoder on the engine eccentric shaft.

b) Setup for ignition and injection test.



c) Control unit for engine.

Figure 5: Images related to control unit has made appropriate a single-rotor test engine.

The original engine is included from two housings, one intermediate housing and two side housings. As shown in Figure 6, primary intake port is on intermediate housing, secondary and auxiliary intake ports are on the side housings. There is no intermediate housing in the experimental engine due to conversion to the single rotor. As shown in Figure 6, by removing the intermediate housing, in single rotor engine, instead of primary port, two secondary ports and two auxiliary ports are available. So there are 4 intake ports on the experimental engine.

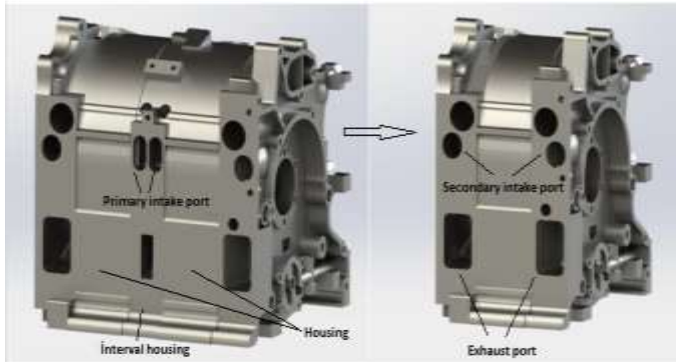


Figure 6: Conversion of two-rotor RX-8 Wankel rotary engine to single-rotor.

In Figure 7a, the design of the engine with its base parts, and in figure 7b, single rotor engine assembled to the dynamometer system is shown.

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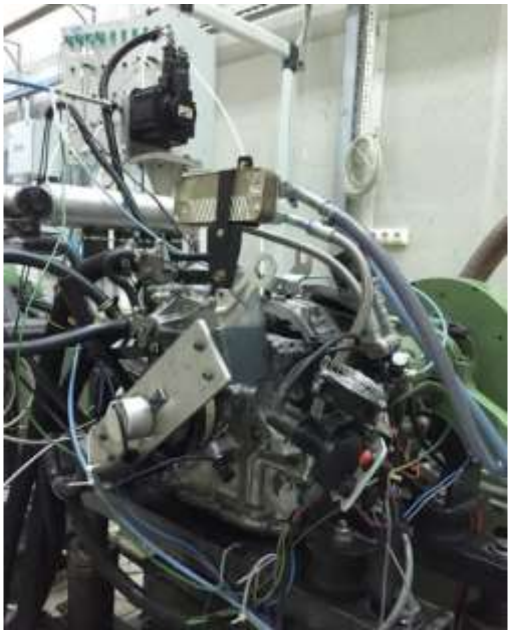


Figure 7: Drawing in the Solidworks of the single-rotor test engine consisting of essential parts (a), Single-rotor prototype test engine (b).

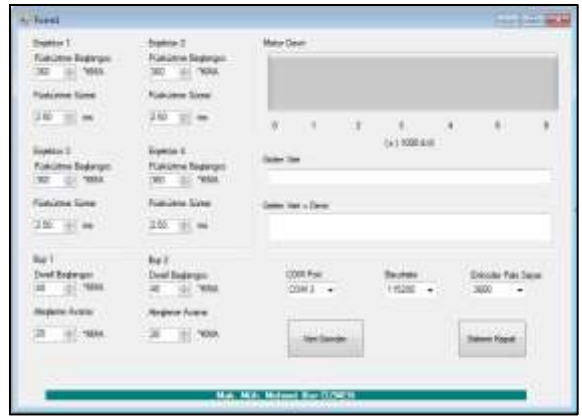
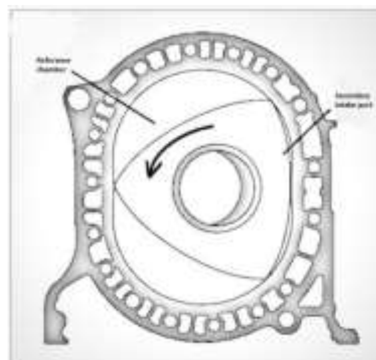
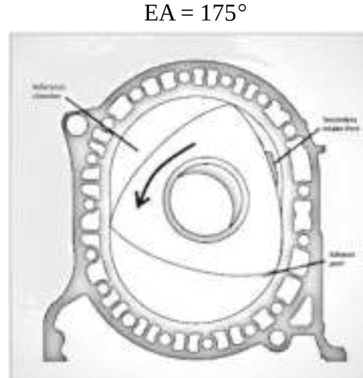


Figure 8: Interface created for the Wankel test engine control unit.



EA = 175°



EA = 225°

RESULTS AND DISCUSSION

Effect of Different Injection Time on Engine Performance and Emissions

In the first step, the test of the existent injectors in terms of injection angle and flow rate characteristics has been performed; then, it is found that the measured parameter are close to the given parameter in the catalogue.

The main injector used in the RX8 engine with "Denso" brand, works under the condition of 13.5 volts nominal voltage, 1 Ampere current and 2.5~7 bars injection pressure. Fuel line pressure in original engine is between 3.75 and 4.5 bars [11]. All experiments have been done with 3.80 bars fuel line pressure.

In experiments only secondary intake channel and one injector has been used. The engine speed is measured by the encoder connected to the eccentric shaft. In Figure 8, the interface of the control unit is shown which can control the four injectors. The entry variables are number of active injectors, injection start time and injection duration.

Experiments are performed in different point in terms of EA (25, 75,125, 225, 275, 325 and 340 EA points). The zero point is the end of the compression top dead center. The experiment has been done in 2000 rpm and 10kW power with stoichiometric fuel-air mixture (λ=1). The position of rotor in different angles is shown in the Figure 9.

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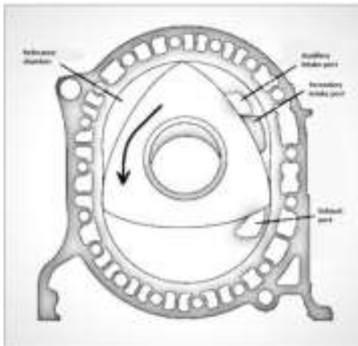
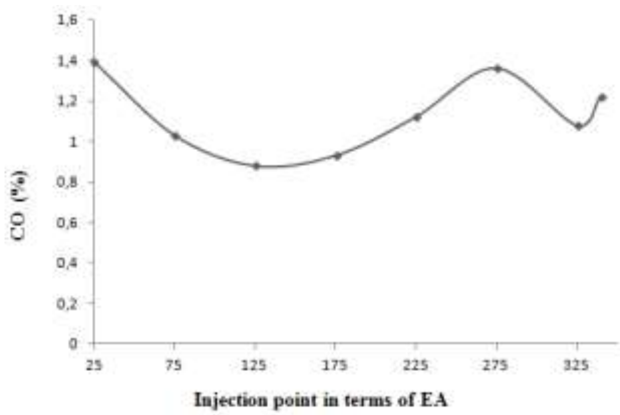
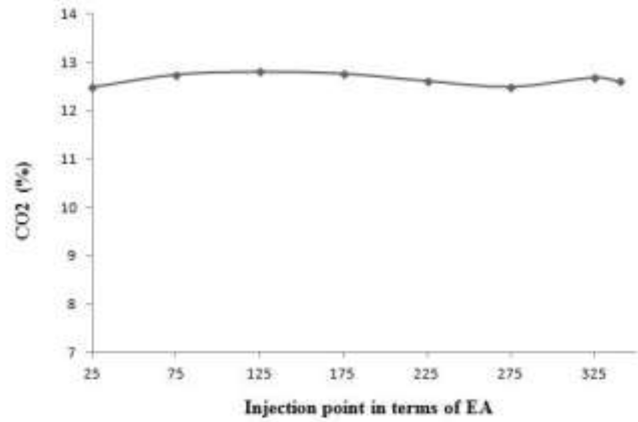


EA = 275°

Figure 9: Spraying of the injector at different angles of the eccentric shaft.

In Figure 9, rotor positions and intake opening areas according to injection timing are shown. The secondary intake port is started to close at 25 and 75 EA points, at 125 EA it is completely closed. At 175 EA, the secondary intake port is slightly opened, at 225 and 275 EA's it is going to be opened, and at 325 EA it is fully open. In the end, the secondary intake port starts to close at 340 EA.





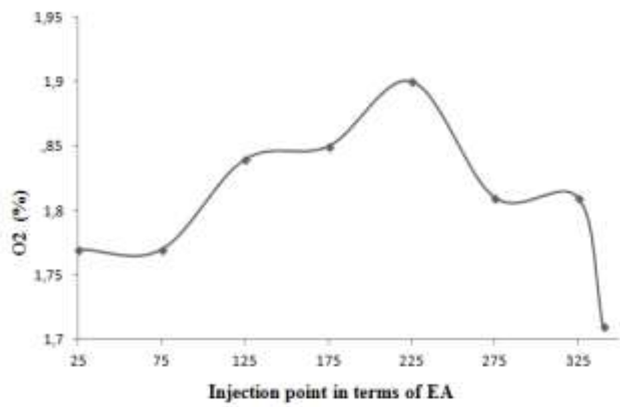


Figure 10: The effect of injection starting time on exhaust emissions.

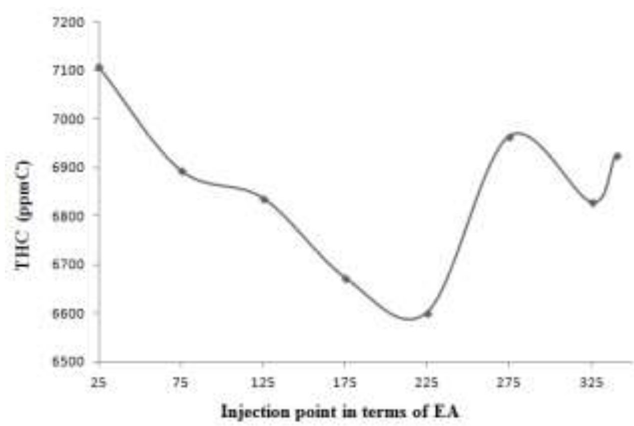


Figure 10 (continue): The effect of injection starting time on exhaust emissions.

As could be seen in Figure 10, changing the injection time does not have sensible effect on CO and CO2 emissions. But, it

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affects the HC emission; because by changing the injection time, the fuel-air mixture formation will be affected. If fuel does not be injected in correct time, some of the fuel droplets could not vaporized; this result to incomplete combustion and increase of HC emission.

Hydrocarbon (HC) emission is the product of unburned fuel and residual oil. Amount of hydrocarbon is function of the temperature and oxygen. By analyzing Figure 10 c and 10 d, by raising the amount of oxygen, the amount of HC decreases and combustion goes to better condition. This is may be due to the small increase of air although in the test it is tried to fix at stoichiometric.

In Figure 10, it could be seen that the injection time between 200 and 225 EA's has the smallest level of HC emission.

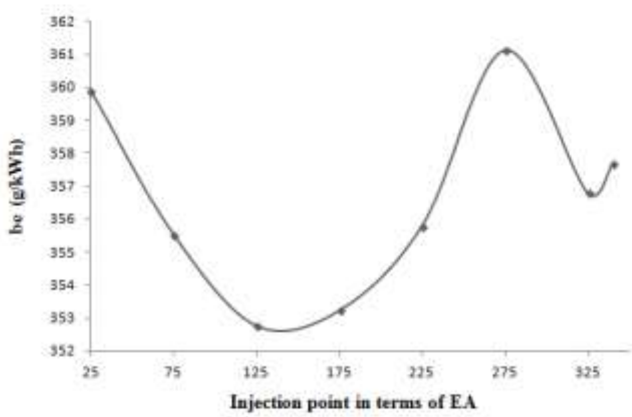

Figure 11: Effect of the specific fuel consumption of the spray at different angles of the eccentric shaft.

Minimum amount of specific fuel consumption is obtained at 125 EA point. But changing the injection time has not strong effect on specific fuel consumption. By looking at the diagram it could be seen that between the 125 and 225 EA's the specific fuel consumption is lower than other points. At these points, by improving the combustion the amount of THC and CO emissions decrease and the amount of CO2 increases.

Effect of Different Excess Air Coefficients on Performance and Emissions in the Single-Rotor Wankel Test Engine.

Generally, in gasoline engines stoichiometric ratio (λ=1) is desired for the mixture, except engine start, acceleration or other different conditions. Almost all of the vehicle engines in the markets are expected to work around stoichiometric (λ=1) condition. Due to this, the mixture sending to the combustion chamber should be completely homogeneous and should not be changed from cycle to cycle. Usually, gasoline engine maximum power is obtained with the excess air coefficient around λ = 0.9. If we want to work in the economic conditions, in this case it should be valued at λ = 1.1. By searching the literature and market, we could not find any value for the excess air coefficient for RX-8 Wankel engine. Generally, rich mixture condition is estimated to be about the λ=0.8 - 0.9 for this engine. In experiments, it has been tried to find the effect of changing the excess air factor on fuel consumption and specially emissions. Experiments are done in different values of λ (0.9, 1 and 1.18) and at 3000 rpm and 9 kW power.

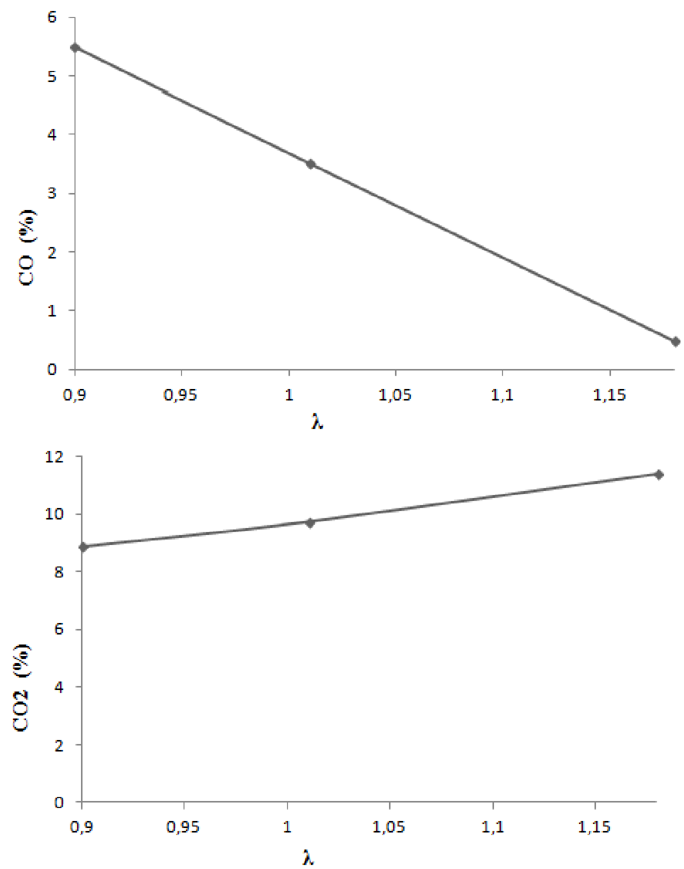

Figure 12: CO2 emission for different excess air coefficient (3000 rpm, 9 kW).

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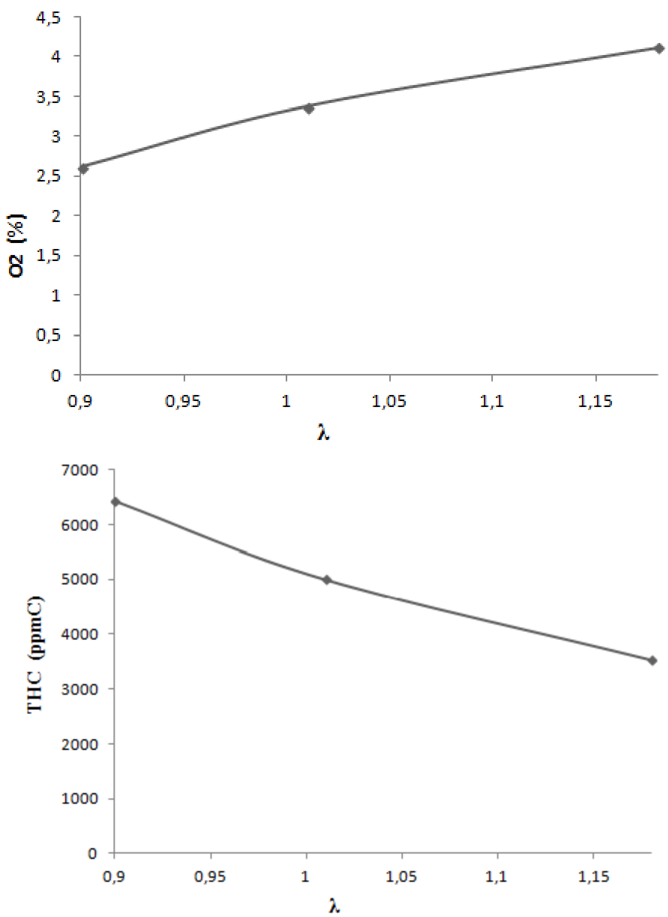

Figure 12 (continue): The effects of emissions at the different excess air coefficient (3000 rpm, 9 kW).

Ignition capability of the mixture will reduce by increasing the excess air coefficient. However, for reducing the CO emission it is necessary to increase the excess air coefficient as much as possible. By this way, needing amount of oxygen for conversion of CO to CO_2 will be supplied. In the regions where the flame spread, CO emissions will be reduced again due to CO emission will be converted to CO2 emission because of excess oxygen. As shown in the Figure 12, by leaning the mixture, the concentration of the CO emission decreases and CO_2 increases. The expectation was decrease of CO2 concentration with higher excess air coefficient. This is may be due to the low load working condition of the engine.

HC emissions also reduce by increasing of excess air coefficient and consequently by providing sufficient oxygen for combustion. However, when λ arises from a certain value, HC emissions again start to increase because the flame will extinguish sooner in the combustion chamber. HC emissions also increase in regions beyond the reach of the flame. As shown in the Figure 12, when excess air coefficient increases, HC emissions are reduced [12-14].

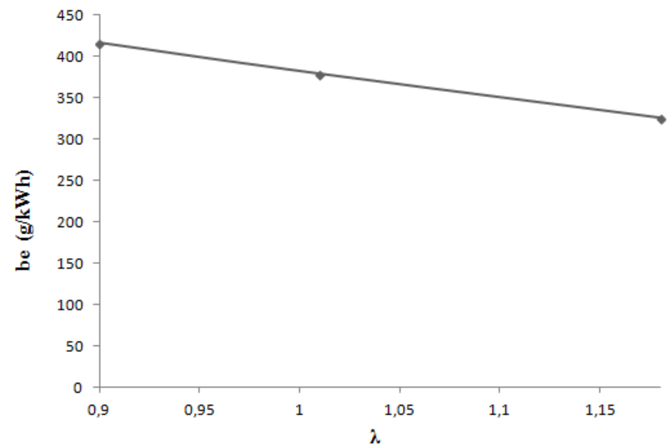

Figure 13: The effects of specific fuel consumption of the different excess air coefficient.

By looking at the diagram obtained from experimental data, it could be seen that fuel consumption decreases by leaning the mixture. The obtained fuel consumption is similar to the values which are published in the literature [15-18].

CONCLUSIONS

In this study, available two-rotor in the RX-8 Wankel engine is converted to single rotor and its systems and units undergone refurbishment or re-manufacture. Engine's many parts such as cooling system, lubrication system, intake and exhaust manifolds and many mechanical parts like eccentric shaft and control unit of the engine has been changed. As result, the conversion process has been completed to test the single-rotor engine. This engine has tested by connecting to the braking system and works successfully. Scope of the work, some preliminary experiments has been made on the engine.

Fuel consumption and exhaust emissions have been investigated for the engine by spraying fuel through the injector in the different angles of the eccentric shaft. Experiments have been made in determinate spray points with stoichiometric mixture ($\lambda = 1$), 10 kW power and 2000 rpm. HC emissions and fuel consumption have shown to be low in the vicinity eccentric shaft angle between 200 and 225°. In the next experiment, the effects of specific fuel consumption and exhaust emissions have been examined for the different excess air coefficients at constant load and speed. In experiments we have realized that at the 3000 rpm,

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9 kW power and λ=0.90, 1 and 1.18. HC emissions and fuel consumption have reduced by leaning the mixture.

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NOMENCLATURE

TDC	Top Dead Center
EA	Eccentric Shaft Angle

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